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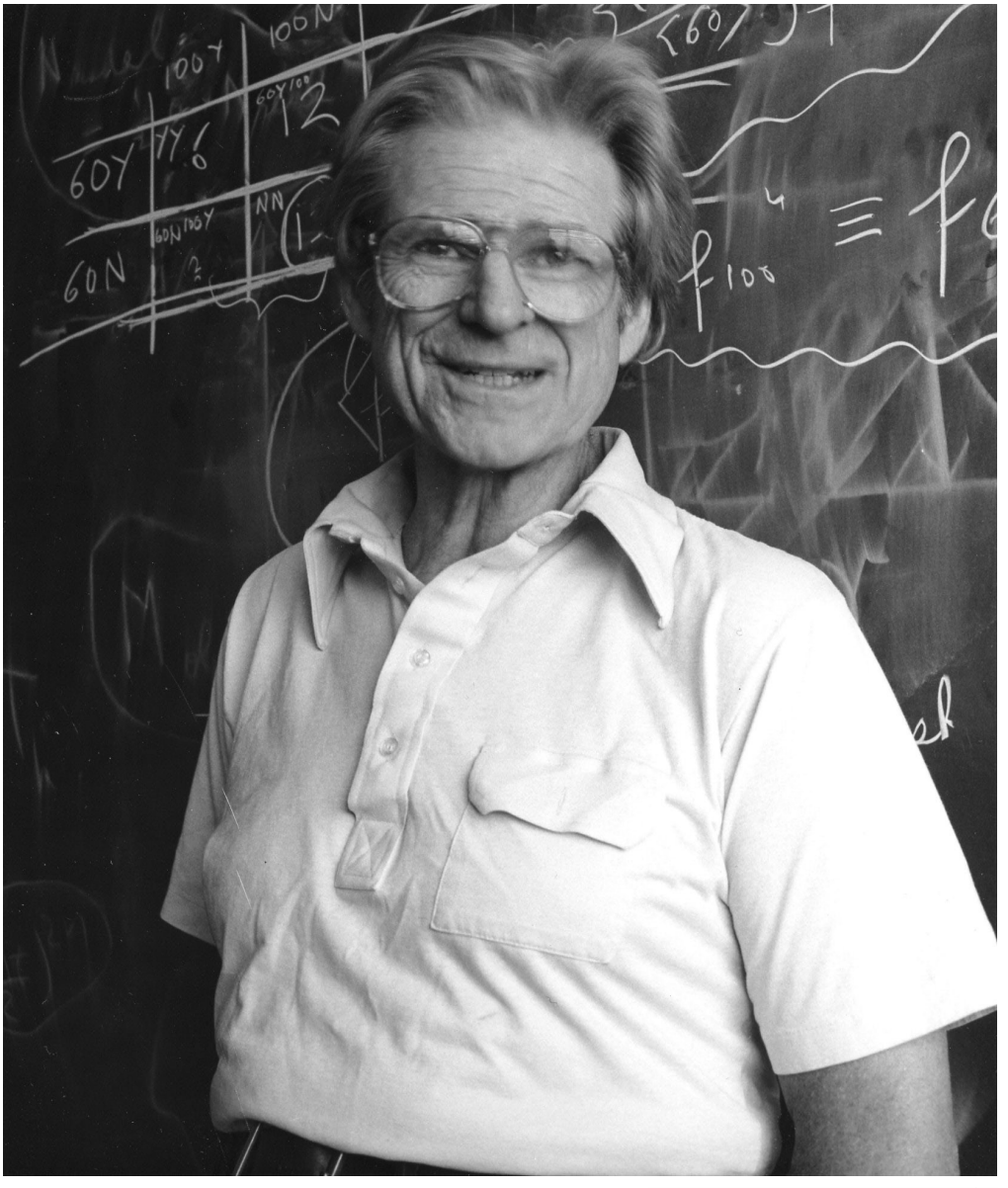

Ed Salpeter

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Elected ForMemRS 1993

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Edwin E. Salpeter was a towering figure in twentieth-century astrophysics. Among his major scientific accomplishments is his 1955 paper 'The luminosity function and stellar evolution', where he first derived the empirical stellar initial mass function and estimated the probability for the creation of stars of given mass at a particular time, known as the Salpeter initial mass function. Just before this major achievement he had explained how giant stars burn helium to form carbon in the triple-alpha process, in which three helium nuclei combine to form carbon. This crucial step opened the path for the formation of elements as heavy as iron in the core of the stars. Salpeter showed the way to put physics into astronomy, and astrophysics has made enormous strides to understand the Universe. He once observed that most successful scientists are golf players; that is, they map out their own strategy and then write a unified theory. Salpeter said that he belonged to the minority of scientists who are Ping-pong players that react to influences from outside players. This approach made Salpeter a generalist.

Salpeter was born in Vienna in December 1924 and attended elementary school there. He then attended the *Gymnasium* and was at the top of his class when on 10 November 1938 the Nazi regime tried to arrest him because he was Jewish. He went into hiding and then fled to Australia with his family. His father was also a physicist who in his youth was a close friend of Erwin Schrödinger (ForMemRS 1949). In Australia, Salpeter attended the Sydney Boys High School, where he had to work very hard and graduated at the age of 16 years with honours. He once said that he had a great time studying so hard, and only regretted that he had not had time to learn how to date girls. He excelled in mathematics and science, however, and entered the University of Sydney to study physics. He wrote a master's thesis on field theory and won a scholarship to go to graduate school in Great Britain.

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He entered Birmingham University in the fall of 1946 and was a student under Rudolf Peierls FRS. His research was centred on quantum electrodynamics, but he also worked on nuclear physics problems. In England in the postwar years Salpeter benefited by interacting with the very distinguished physicists of the time, including Werner Heisenberg, Hans Bethe, Wolfgang Pauli, Paul Dirac and Robert Oppenheimer, and with Fred Hoyle, Herman Bondi and Tommy Gold, all of whom were either current or future members of the Royal Society. He apparently once asked a physics question of Pauli, who answered, 'I don't know how people can be SO stupid', but then gave a real answer patiently and in detail. Pauli was known to be so very direct.

Salpeter became close friends with Bondi, Hoyle and Gold and was initially in favour of their steady-state theory versus the Big Bang. He tried to salvage the steady state from the deluge of new data from the microwave background, but the data finally won.

In 1949, after having received his PhD degree, he moved to Cornell University in Ithaca, New York, as a research associate to work with Hans Bethe. He spent the remainder of his career at Cornell, where he eventually became the J. G. White Distinguished Professor in the Physical Sciences. In 1950 he married Miriam ('Mika') Mark, who later became a professor in neurobiology at Cornell. Soon they had two daughters, Judy and Shelley. Mika died in 2000 after a short illness, and Salpeter subsequently married Antonia (Lhamo) Shouse.

In his early days at Cornell, quantum electrodynamics was an exciting new frontier being explored by Richard Feynman (ForMemRS 1965), Freeman Dyson (FRS 1952) and others. Salpeter enjoyed telling the story of a long calculation of fourth-order vacuum polarization that he, Dyson and a graduate student, Michel Baranger, carried out independently. When the results were compared, Salpeter and Dyson agreed, but the student had a different answer and it turned out that the student was correct.

In the summer of 1953 Salpeter participated in the Ann Arbor summer school (Michigan Symposium on Astrophysics). There he met senior astronomers such as Walter Baade, Leo Goldberg, Allan Sandage (ForMemRS 2001) and George Gamow. Salpeter recalls that he observed but did not emulate Gamow's example of drinking vodka out of a water pitcher—even before lunch. At these meetings Salpeter discussed hydrogen and helium burning in stars, and reactions between carbon and oxygen in more evolved stars.

In his research career Ed Salpeter published more than 350 scientific papers spanning a wide range of topics in physics, astrophysics and neurobiology. He was a generalist and found it easy to apply scientific knowledge from one subdiscipline of physics to another and from the field of physics to other subjects.

Among his most famous works is the 1951 Bethe–Salpeter equation, which is a combination of special relativity with quantum mechanics. In 1957 together with Bethe he published a detailed monograph on quantum mechanics that is still being used today. In the 1950s Salpeter became interested in nuclear astrophysics and studied the energy-producing reactions in red giant stars. Beginning in 1951, he started spending the summers at the California Institute of Technology working with Willy Fowler at the Kellogg Radiation Laboratory, where he was motivated to think about nuclear astrophysics; as mentioned above, he showed that one could form carbon atoms by having a beryllium atom absorb a helium atom, and thus opened the possibilities of nucleosynthesis of the heavier elements in the core of the stars. Later, Fred Hoyle suggested that carbon must have a resonant energy level to speed up this process. Willy Fowler at California Institute of Technology was then able to verify this prediction experimentally.

Still in the 1950s Salpeter calculated how many massive stars were born and have died over the lifetime of our galaxy and from this he derived the initial mass function for star formation (birth-rate function of stars) that has become one of his most famous scientific results.

In 1958 Bill Gordon, an electrical engineer at Cornell University, proposed to build the Arecibo Ionospheric Observatory in Puerto Rico to study incoherent backscatter of radio waves from the free electrons in the ionized upper atmosphere. In a 1960 paper, 'Electron density fluctuations in a plasma', Salpeter showed that the backscatter would give a frequency shift related to the plasma frequency. This turned out to be a convenient way to measure the electron density in laboratory plasma and has had numerous applications ever since.

In a 1964 paper, 'Accretion of interstellar matter by massive objects', Salpeter showed that gas accreting onto a black hole is an effective source of radiant energy. The paradigm that quasars were accreting black holes is now well accepted, and models based on this idea allow the observational study of these enigmatic objects. He also explained how molecules form on interstellar dust grains. Molecular hydrogen in the galaxy is thought to be formed largely by this mechanism. With the late John Bahcall he predicted the sharp absorption Lyman alpha lines in the spectra of quasars. With Dave Stevenson (FRS 1993) he studied the questions of solubility, nucleation of droplets, and gravitational separation of helium and hydrogen in the major planets.

In the late 1970s and beyond, Salpeter was attracted to the study of galaxies, galaxy groups, dark matter and binary galaxies, in the course of which he collaborated with his radio-astronomy colleagues and their students. He collaborated with this author and his students (29 co-authored papers) to study the physical parameters of the interstellar diffuse matter using 21 cm neutral hydrogen observations made with the Arecibo radiotelescope. Many times during our research meetings Ed would try to describe some very complicated process and my students and I would pretend to understand him, yet always later it was clear that Ed had the correct intuition.

Salpeter was a generalist with incredible insight who enjoyed switching fields and working on various different topics. In his later years he worked with his daughter Shelley (a physician) in medicine and infectious diseases, and collaborated with her on epidemiology and statistical analysis of clinical trials. Some of this work also involved his grandson, Nicholas Buckley. He also continued his wife's work (after her death in 2000) in neurobiology.

In 1984 we celebrated Ed's 60th birthday with a major symposium at Cornell University, where more than 300 scientists from all over the world came to celebrate him and his science. I was then chair of the department, and I recall that we had to change banquet halls three times as the number of registered participants kept increasing. Among the speakers were Willy Fowler, Hans Bethe, John Bahcall, Kip Thorne, Martin (now Lord) Rees (PRS 2005–2010), Vera Rubin, Riccardo Giacconi, Philip Morrison and Freeman Dyson. In 1986 the proceedings of this meeting were published in a book titled *Highlights of modern astrophysics: concepts and controversies,* edited by S. Shapiro and S. Teukolsky. The foreword of this book was written by the late Cornell cosmologist Thomas Gold, who related how he first met Salpeter:

> In 1949 I spent an afternoon walking through the backs of the colleges in Cambridge (the real Cambridge, as they call it), with an Austro-Australian postdoc, discussing such matters as the origin of the universe, the nature of fundamental particles, and the progress in mathematical physics and chatting about many of the personalities of the day involved in those subjects. My visitor had come from Birmingham, where his studies were being guided by the great physicist Rudi Peierls. He was visiting Cambridge to broaden his acquaintance with the British science in physics, and he expressed a certain interest also in astronomy.

> My recollection of this meeting, and of the discussion, is very clear in one respect. He was a young man who gave me the impression of being a simple Austrian country boy, and yet it became evident from his conversation that he had acquired considerable knowledge and sophistication in physics, and he clearly had gained access to the inner circles of physics in England. I have come since to realize that it is just this unpretentious attitude (without having much to be unpretentious about!) which is the hallmark of Ed Salpeter, and which has made him a pleasant colleague and collaborator, and such an attractive teacher.

In 2004 a special symposium was organized by his students and colleagues near Siena, Italy, to celebrate the 50 years of Ed's publication of the initial mass function that coincided with his 80th birthday. The symposium proceedings, *The initial mass function: 50 years later*, was dedicated to Ed: '[F]rom whom we have learned so much, to his insight and friendship'.

During his long career, Salpeter had many offers from major research universities to establish theoretical physics groups and also to become chair of major physics departments. In all such cases, at the end he refused to move from Cornell even though he complained that the academic salaries were low. The only advantage he and his wife could see was that with a higher salary they could afford to have pure maple syrup rather than the cheaper imitation kind. In fact every time we had pancakes at his house we always had pure maple syrup.

During his academic career Salpeter mentored more than 50 graduate students, including Hubert Reeves, Bruce Tarter, Vahe Petrosian, Gilles Beaudet, Robert Gould, Nicholas Krall, Bruce Draine, David Stevenson, Hugh van Horn, David Hollenbach, Kris Davidson, Richard Lovelace, Allen Boozer, Paul Joss, George Helou, Jonathan Katz, Nathan Krumm, William Newman, Lars Bildsten, Lyle Hoffman and Edvige Corbelli.

During his teaching career Salpeter taught primarily graduate courses, including stellar structure and interstellar matter. He was an enthusiastic teacher. Although he could fill large blackboards with long equations if needed, his intuition was most often expressed in terms of order-of-magnitude estimates. One of his favourite questions was: 'What dimensionless number is unity in this regime?' Students would rarely ask questions because few were able to follow what he was talking about. One had to go home and spend hours in order to derive even a simple equation that Salpeter had taken for granted. I also recall that when collaborating with Salpeter and with our students in research, often he would write a section of the paper that neither I nor our students would be able to follow. In one paper the *Astrophysical Journal*'s referees were not able to follow a section that he wrote, and the paper was published without that section. Three years later, when we had much more data, it was evident that what we were seeing was what Salpeter had concluded in the section that was omitted. His deep insight was almost frightening.

When in town Salpeter rarely missed any physics or astronomy colloquia. The speakers were aware of his presence and were always careful not to make unjustified assumptions. Yet Salpeter would normally ask very simple questions at the colloquia; it was later when talking with the visitors one on one in his office that he would ask the very embarrassing questions. This was unlike Tommy Gold, who was also usually present at the colloquia. Tommy would stop the speaker halfway through a sentence and describe his new theory from the data the visitor was showing.

Salpeter was not born to be an academic administrator, and he knew it. Yet for a short period of time he agreed to be the director of Cornell's Center for Radiophysics and Space Research that Tommy Gold had founded in 1959. One day he forgot his very old brown leather briefcase in my office, and remembered it three days later. Once at a lunch meeting he

unintentionally proceeded to eat the apple of the person sitting next to him. He was appointed to many committees and boards and was a member of JASON, doing classified defence work. He analysed the antiballistic missile defence programmes in the 1960s and debunked various ABMD (AEGIS Ballistic Missile Defense) schemes. He resigned from JASON after it became clear that the United States was getting involved in the Vietnam war. He was a member of the National Science Board (the board of the National Science Foundation) from 1978 to 1984.

Among his many honours, the Swedish Royal Academy of Sciences presented him with its Crafoord Prize, shared with Fred Hoyle (1997). He also received the Gold Medal of the Royal Astronomical Society in the UK (1973), the J. R. Oppenheimer Memorial Prize (1974), the H. N. Russell Lectureship of the American Astronomical Society (1974), the Catherine Bruce Medal of the Astronomical Society of the Pacific (1987), and the Dirac Memorial Medal (1996). He was also awarded DSc degrees from the University of Chicago, Case Western Reserve University, Sydney University, and the University of New South Wales. In 1967 he was elected to the National Academy of Sciences.

In his long and spectacularly productive life Ed Salpeter remained a modest person who loved to have a good time—on the ski slopes or throwing large parties at his home. He also enjoyed listening to music and all the famous operas. He enjoyed working closely with his many graduate students, who have been deeply inspired by his keen intuition in physics and astrophysics. He died of leukaemia on 26 November 2008 at his home in Ithaca, New York.

We all respected him and we loved him. He was a towering figure in physics and astrophysics.

Acknowledgements

The frontispiece photograph was taken in about 1995 by Cornell University Photography and is reproduced with permission.

Selected bibliography

1949 Nuclear induction signals for long relaxation times. *Proc. Phys. Soc. A* **63**, 337.
1951 (With H. A. Bethe) A relativistic equation for bound-state problems. *Phys. Rev.* **84**, 1232.
1952 (With H. Bondi) Thermonuclear reactions and astrophysics. *Nature* **169**, 304.
Nuclear reactions in stars without hydrogen. *Astrophys. J.* **115**, 326.
Nuclear reactions in the stars. I. Proton-proton chain. *Phys. Rev.* **88**, 547.
1953 The Lamb shift for hydrogen and deuterium. *Phys. Rev.* **89**, 92.
1954 Electron screening and thermonuclear reactions. *Aust. J. Phys.* **7**, 373.
1955 The luminosity function and stellar evolution. *Astrophys. J.* **121**, 161.
1957 (With H. A. Bethe) *Quantum mechanics of one- and two-electron atoms*. Berlin: Springer-Verlag.
1959 The rate of star formation in the galaxy. *Astrophys. J.* **129**, 608.
(With H. Reeves) Nuclear reactions in stars. IV. Buildup from carbon. *Phys. Rev.* **116**, 1505.
1960 Scattering of radio waves by electrons above the ionosphere. *J. Geophys. Res.* **65**, 1851.
Electron density fluctuations in a plasma. *Phys. Rev.* **120**, 1528.
1961 Energy and pressure of a zero-temperature plasma. *Astrophys. J.* **134**, 669.
1963 (With T. Hamada) Models for zero-temperature stars. *Astrophys. J.* **134**, 683.
(With R. J. Gould) The interstellar abundance of the hydrogen molecule. I. Basic processes. *Astrophys. J.* **138**, 395.

(With R. J. Gould & T. Gold) The interstellar abundance of the hydrogen molecule. II. Galactic abundance and distribution. *Astrophys. J.* **138**, 408.

1964 (With H. Y. Chiu) Surface x-ray emission from neutron stars. *Phys. Rev. Lett.* **12**, 413.
(With J. P. Cox) Equilibrium models for helium-burning stars. III. Stars of small mass. *Astrophys. J.* **140**, 485.
Accretion of interstellar matter by massive objects. *Astrophys. J.* **140**, 796.

1965 (With J. N. Bahcall) On the interaction of radiation from distant sources with the intervening medium. *Astrophys. J.* **142**, 1677.

1966 (With J. N. Bahcall) Absorption lines in the spectra of distant sources. *Astrophys. J.* **144**, 847.

1967 Interplanetary scintillations. I. Theory. *Astrophys. J.* **147**, 433.
(With V. Petrosian & G. Beaudet) Photoneutrino energy loss rates. *Phys. Rev.* **154**, 1445.
(With H. S. Zapolsky) Theoretical high pressure equation of state including correlation energy. *Phys. Rev.* **158**, 876.
(With G. Beaudet & V. Petrosian) Energy losses due to neutrino processes. *Astrophys. J.* **150**, 979.

1969 (With H. M. Van Horn) Nuclear reaction rates at high densities. *Astrophys. J.* **155**, 183.
(With C. B. Tarter) The interaction of x-ray sources with optically thick environments. *Astrophys. J.* **156**, 953.
(With H. S. Zapolsky) The mass-radius relation for cold spheres of low mass. *Astrophys. J.* **158**, 809.

1971 Central stars of planetary nebulae. *Annu. Rev. Astron. Astrophys.* **9**, 127.
(With M. M. Salpeter) Resolution in electron microscope radioautography. II. Carbon 14. *J. Cell Biol.* **50**, 324.

1976 (With D. J. Stevenson) Interior models of Jupiter. In *Jupiter, studies of the interior, atmosphere, magnetosphere and satellites* (ed. T. Gehrels), pp. 85–112. Tucson: University of Arizona Press.

1977 (With M. M. Salpeter & H. C. Fertuck) Resolution in electron microscope autoradiography. III. Iodine-125 and heavy metal staining. *J. Cell Biol.* **72**, 161.
(With J. M. Dickey & Y. Terzian) Temperature distribution of neutral hydrogen at high galactic latitudes. *Astrophys. J.* **211**, L77.
Formation and destruction of dust grains. *Annu. Rev. Astron. Astrophys.* **15**, 267.

1978 Planetary nebulae and the interstellar medium. In *Planetary nebulae, observation and theory* (ed. Y. Terzian), pp. 333–339. Dordrecht: Reidel.

1979 (With G. Helou & N. Krumm) Membership and velocity distribution in the core of the Virgo Cluster. *Astrophys. J. Lett.* **228**, L1.
(With J. M. Dickey & Y. Terzian) Interpretation of neutral hydrogen absorption. *Astrophys. J.* **228**, 465.
(With B. T. Draine) Destruction mechanisms for interstellar dust. *Astrophys. J.* **231**, 438.

1982 (With G. Helou & Y. Terzian) Neutral hydrogen in binary and multiple galaxies. *Astron. J.* **87**, 1443.
(With G. L. Hoffman) Dynamical models and our Virgocentric deviation from Hubble flow. *Astrophys. J.* **263**, 485.

1983 Free fall onto magnetized neutron stars. *Aust. J. Phys.* **36**, 745.
(With H. A. Bethe) The Nobel Prize in Physics to W. Fowler and S. Chandrasekhar for 1983. *Science* **222**, 881.

1986 (With S. E. Schneider & Y. Terzian) High-resolution observations of the intergalactic H I cloud in the M96 group. *Astron. J.* **91**, 13.

1987 (With T. Gaetz & G. Shaviv) Gasdynamical stripping of elliptical galaxies. *Astrophys. J.* **316**, 530.
Science and technology of directed energy weapons. *Rev. Mod. Phys.* **59** (3, pt 1), S1–S202.

1988 (With E. Corbelli) Galactic fountains and extended H I disks. *Astrophys. J.* **326**, 551.

1990 (With L. Bildsten & I. Wasserman) A semi-classical model for breakup reactions of light nuclei: ^{4}He(p, pn)^{3}He. *Nucl. Phys. A* **516**, 77.

1991 (With P. Lenzuni & D. F. Chernoff) Rosseland and Planck mean opacities of a zero-metallicity gas. *Astrophys. J. Suppl.* **76**, 759.

1992 (With L. Bildsten & I. Wasserman) The fate of accreted CNO elements in neutron star atmospheres: X-ray bursts and gamma-ray lines. *Astrophys. J.* **384**, 143.

1994 (With J. N. Chengalur & Y. Terzian) Dynamics of binary galaxies. II. Close pairs. *Astron. J.* **107**, 1984.

1996 Reminiscences of George Gamow and nuclear astrophysics. *Astron. Astrophys. Trans.* **10**, 3.

1997 Neutron stars before 1967 and my debt to Chandra. *J. Astrophys. Astron.* **17**, 77.
(With D. Lai) Hydrogen phases on the surface of a strongly magnetized neutron star. *Astrophys. J.* **491**, 270.
1998 (With S. R. Salpeter) Mathematical model for the epidemiology of tuberculosis, with estimates of the reproductive number and infection-delay function. *Am. J. Epidemiol*. **142**, 398–406.
2000 (With T. E. Nordgren, J. N. Chengalur & Y. Terzian) The 1.0 megaparsec galaxy pair sample in low density regions. *Astrophys. J.* **504**, 176.
2002 A generalist looks back. *Annu. Rev. Astron. Astrophys*. **40**, 1.
2005 Fallacies in astronomy and medicine. *Rep. Prog. Phys.* **68**, 2747.
Scientific integrity in government and ballistic missile defense. Forum on Physics and Society of the American Physical Society, October 2005; see <www.aps.org/units/fps/newsletters/2005/october/articles.html#salpeter> (accessed 7 September 2009).
2006 (With S. R. Salpeter & N. S. Buckley) Meta-analysis: anticholinergics, but not β-agonists, reduce exacerbations and respiratory mortality in COPD. *J. Gen. Intern. Med*. **21**, 1011.